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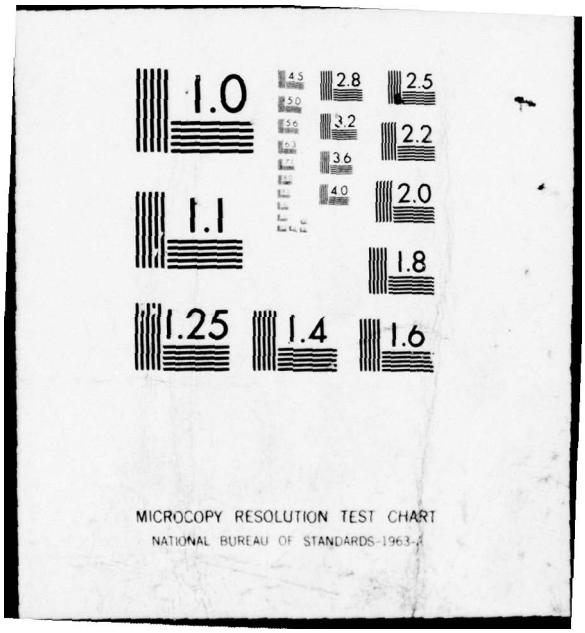
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AN UPDATE

SPECIAL REPORT

STRATEGIC STUDIES INSTITUTE
US ARMY WAR COLLEGE
Carlisle Barracks, Pennsylvania

MATERIALS VULNERABILITY OF THE UNITED STATES--AN UPDATE

by

Alwyn H. King

30 April 1977

DISCLAIMER

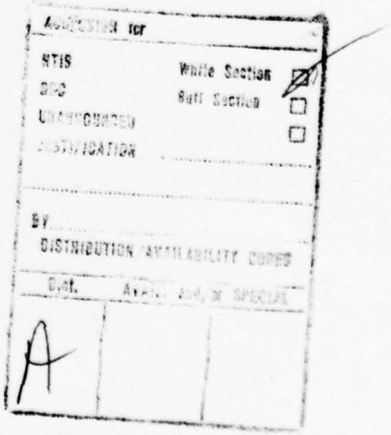
The views of the author do not purport to reflect the position of the Department of the Army or Department of Defense.

FOREWORD

This special report discusses the problem of availability of nonenergy materials in the United States, and reviews some recent Government and industry efforts to deal with the situation. The author views the US materials dilemma as being more complex than simply a scarcity of certain materials, or monopolistic and coercive actions by foreign materials suppliers. He considers materials availability problems such as insufficient research and development, inadequate recycling, and the lack of an established dialogue between materials R&D and the materials supply and demand communities. The report concludes that, although it is unlikely that shortages of any critical material will be the direct cause of armed conflict in the foreseeable future, such shortages could exacerbate other areas of international friction and could contribute to the outbreak of hostilities.

This special report was prepared as a contribution to the field of national security research and study. As such, it does not reflect the official view of the College, the Department of the Army, or the Department of Defense.

JOSEPH E. PIZZI
Colonel, Infantry
Director



BIOGRAPHICAL SKETCH OF THE AUTHOR

DR. ALWYN H. KING joined the Strategic Studies Institute in 1973. He holds an engineering degree from McGill University, an MS from Columbia University and an MBA from Babson College, and a doctorate from Stuttgart Technical University in Germany. He has been associated with the Brunswick Corporation Research and Development Laboratories and with Arthur D. Little, Inc., and is the author of a number of articles and research reports in the literature of both the physical and social sciences.

MATERIALS VULNERABILITY OF THE UNITED STATES--AN UPDATE

Complexity of the Problem

The 1973-74 oil embargo and resultant price hikes stimulated great interest and concern about possible shortages of other nonrenewable material resources. This concern, plus the myriad of recent theories, predictions and projections for the future condition of the United States and the world, point up a complex matrix of materials, environmental and developmental problems. The combined effects alluded to in the books Silent Spring,[1] World Dynamics,[2] The Limits to Growth,[3] et al., plus the very real economic problems of inflation, unemployment, and actual shortages of some basic industrial materials present a dim and confusing picture of the future. Despite the complexity of our situation, however, some semblance of an understanding of the interaction between basic materials problems and other influences has begun to emerge.

An earlier Military Issues Research Memorandum, published by the Strategic Studies Institute, US Army War College, discussed the implications of scarce resources in terms of US vulnerability to economic, political or military effects due to coercive pressures by suppliers of critical materials in domestic short supply.[4] This paper updates the materials availability problem on a broader basis, and reviews government and industry efforts to deal with the situation. The US materials dilemma is of an institutional nature, with issues that are far more complex than problems associated simply with physical scarcity of certain materials, or monopolistic and coercive actions by foreign materials suppliers. Materials availability problems stem in part

from insufficient R&D to develop new resources, extraction processes and substitutes; inadequate recycling; and even a "shortage mentality" causing the accumulation of excessive inventories and resulting short-term scarcity of certain materials in some industries. The institutional issue basic to this dilemma is the lack of an established dialogue between the materials R&D and the materials supply and demand communities on the subject of materials availability.

Efforts to Find Solutions

While both the "doomsters" and the "cornucopians" are busy describing, respectively, the dark cloud and its silver lining, a relatively small group of more pragmatic individuals have been attempting to sort out and come to grips with the many ramifications of the overall problem. Two recent conference/workshop meetings have contributed substantially to efforts to bring order from chaos, and further define the problem which confronts us.

Materials Shortage Workshop

A Department of Defense Materials Shortage Workshop in January 1975 addressed materials shortage problems as related to the DoD in three major dimensions:

1. The heavy dependence on foreign imports of critical materials.

2. The US economic situation which frequently inhibits the capitalization of new plant equipment.

3. The impact of the application of Environmental Protection Agency (EPA) and Occupational Safety and Health (OSHA) regulations on industry, which has resulted in shut-down of industrial facilities, some of which are essential to DoD's operational needs.*

The agenda of this workshop included two days of briefings and conferences on the above three topics, followed by panel discussions designed to further

*Memorandum from Director of Defense Research and Engineering to Assistant Secretaries of the Military Departments, subject: Materials Shortages, dated December 20, 1974.

identify problem areas and to clarify the roles of various government agencies and possible DoD actions to seek technological solutions to material shortage problems.

The workshop sessions developed an extensive list of suggested actions which were distilled by the DoD Materials Shortages Steering Committee to arrive at five basic recommendations:

- Establish strong coordination with other involved Federal agencies.
- Develop methodology for establishing a shortages data base.
- Expand the current technology base and manufacturing programs to emphasize principles of conservation.
- Participate in planning of the national stockpile.
- Participate in the National Commission on Supplies and Shortages.

The first recommendation was implemented by inviting a number of Federal agencies to membership on the DoD Materials Shortages Steering Committee. The Committee then commenced work on the other, longer-term recommendations, which were in various stages of implementation at the time of the second conference in February 1976.

Workshop on Government Policies and Programs Affecting Materials Availability.

A comparison of the titles and agendas of the two DoD workshop/conferences reflects the growing realization that the "materials" problem involves much more than just a shortage of critical materials. The true nature and scope of the situation is indicated by the list of issues discussed during the working panel sessions of this second conference:

- Erosion of the Industrial Base.
- Early Warning/Materials Information Systems.
- Materials Research and Development.
- Environmental, Safety and Health Regulations.

- National Stockpile.
- US Transportation System.
- Materials Education.
- Specific Materials Availability Problems.
- Conflicts in Government Policies and Programs.

James M. Owens, Department of Commerce representative at the meeting, perceptively broadened the definition of "shortage" to include all potential supply aberrations, or dislocations, of materials and commodities.

Congressional and Industrial Interest

These conferences and other discussions and publications on our materials position have generated a deep and continuing interest in national materials policy in the US Congress. Recently, congressional interest has accelerated in recognition of the basic importance of materials to the nation's health and economy, anxiety over shortages abroad, threats of possible embargoes on critical materials, and general uncertainty over future supply and conservation of materials. It has become apparent that the nation has no accurate assessment of its domestic materials resources, is not making the most efficient use of those resources which are known, and has no adequate policy for development and use of resources on Federal lands. There is alarm over the vast quantities of materials lost through disposal as solid waste, most of which remains inaccessible for a number of economic, political, institutional, and technological reasons.

Concern over these problems has taken a variety of forms as evidenced by hearings held during the 94th Congress and the more than 500 materials-related bills introduced. Legislation focused upon five major areas of interest: improved management of materials; avoidance of future shortages of materials; better means for handling, storing, transporting, and disposing of hazardous

and toxic materials; reclamation of materials from solid waste or the conversion of waste materials to other useful forms, including energy; and stockpiling of selected materials for both strategic and economic purposes.

These and other less obvious areas of concern have surfaced throughout industry, indicating that here, too, there is a growing understanding that the problems go much deeper than simply a matter of running out of mineral reserves. As an example, the corrosion of metals has been recognized as a contributor to materials shortages in three ways:

1. Obviously, corrosion adds to the shortage of materials by the amount of corroded items which must be replaced.

2. The metals required to replace corroded articles must be produced with the expenditure of energy--therefore energy production is an essential term in the overall materials shortage equation.

3. There is the problem which the corrosion engineer must face as the alloying elements and chemicals upon which he relies to mitigate corrosion come into short supply.

It has been estimated that corrosion costs the United States economy at least $35 billion annually.

The "useful life" concept has also emerged, emphasizing the idea that an unnecessarily short life of a product or a piece of equipment represents both a waste of materials and of the energy required in their production and manufacture. A recent "Workshop on Wear Reduction," sponsored by the Congressional Office of Technology Assessment (OTA) concluded that significant increases in product durability could be achieved using available wear control technology. The consensus was that tribology--the branch of science concerned chiefly with improvements in wear control for greater product durability--has not received sufficient attention in US academic, industrial and government institutions.[5]

We now recognize that many materials problems are institutional in nature and involve the complex interaction of supply, demand, economics, politics and international relations, as well as human emotions when considering health, safety and environmental factors.

The National Commission on Supplies and Shortages

In May 1974, Treasury Secretary William E. Simon and Senator Mike Mansfield jointly announced the establishment of a National Commission on Supplies and Shortages. This body was mandated under Public Law 93-426, 93d Congress, September 30, 1974:

> . . . to make reports to the President and the Congress with respect to:
>
> (1) the existence or possibility of any long- or short-term shortages; employment, price or business practices; or market adversities affecting the supply of any natural resources, raw agriculture commodities, materials, manufactured products (including any possible impairment of productive capacity which may result from shortages in materials, resources, or capital investment, and the causes of such shortages, practices, or adversities);
>
> (2) the adverse impact or possible adverse impact of such shortages, practices, or adversities upon consumers, in terms of price and lack of availability of desired goods;
>
> (3) the need for, and the assessment of, alternative actions necessary to increase the availability of the items referred to in paragraph (1) of this subsection, to correct the adversity or practice affecting the availability of any such items, or otherwise to mitigate the adverse impact or possible adverse impact of shortages, practices, or adversities upon consumers referred to in paragraph (2) of this subsection;
>
> (4) existing policies and practices of government which may tend to affect the supply of natural resources and other commodities;
>
> (5) necessary legislative and administrative actions to develop comprehensive strategic and economic stockpiling and inventories policies which facilitate the availability of essential resources;
>
> (6) the means by which information with respect to paragraphs (1), (2), (3), (4) of this subsection can be most effectively and economically gathered and coordinated.[6]

This Commission, comprised of 13 members--four from the Executive Branch, two each from the Senate and the House of Representatives, and five from private life--established a work plan of 16 major tasks designed to determine:

o How the Government can be structured to provide necessary action to prevent shortages or to minimize their adverse impact on the consumer, and

o What role private industry can best play in the formulation and implementation of policies to deal with this issue.

A first draft of the Commission's final report has been completed, and the report is expected to be made available to the public in 1977.

Materials Information Systems.

Studies of systems designed to provide early warning of shortages, and materials information systems in general, are included under the first and last of the six functions of the Commission spelled out above. Among systems under study is The Strategic Materials Management Information Program (SMMIP), developed by Battelle-Columbus Laboratories and based in part on the "vulnerability index" approach.*

The SMMIP grew out of discussions and recommendations at the first DoD Workshop on Materials Shortages in January 1975, and had the specific objective of providing "a continuing resource of authoritative information and data on the adequacy of current and future supplies of selected materials determined to be essential to the military program."[7] By September of 1975, a useful preliminary operating system had been developed at the DoD Metals and

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*The concept of a "relative vulnerability index" to classify critical materials as to vulnerability to coercive acts and pressures was first proposed in the earlier Strategic Studies Institute (SSI) Military Issues Research Memorandum of 1974.

Ceramics Information Center, and there were strong recommendations at the second DoD workshop for further development and implementation of this program, as well as an Early Warning System under development in the Department of Commerce.

Such a data base and early warning system are basic requirements in achieving solutions to our materials problems by helping to anticipate problems and allow timely corrective action. Since funds for such action are limited, a method is needed to monitor the vulnerability of critical materials to supply aberrations, and to insure that priorities for R&D or other corrective measures are realistically communicated and established.

Appendix A describes the current status of the Strategic Studies Institute method of determining a "relative vulnerability index (RVI)," which will allow critical materials to be classified as to vulnerability to military, political or economic pressures, and provide a means of monitoring such vulnerabilities and updating relative values as conditions change for any individual material.

The US Government Stockpile.

Another important function of the National Commission on Supplies and Shortages has been an evaluation of national materials stockpiling policies. The fifth Commission function listed above mandates a study of both strategic and economic stockpiling, and a significant effort has been devoted to this subject.

Three basic questions addressed in this area have been:

1. What would the purpose of an economic stockpile be and what role would it play in the economic market?

2. If an economic stockpile was needed to "facilitate the availability of essential resources," by whom, how, and with what safeguards would it be administered?

3. What role does the current strategic stockpile play in national security and the economic market?

To answer these questions, the Commission has made use of various studies prepared by other Government agencies and two studies by private contractors concerning the administrative requirements of an economic stockpile and the interactions between expected private market behavior and a public materials stockpile held for economic objectives. Methods other than stockpiling, such as international commodity arrangements through which the availability of essential resources can be facilitated, have also been under review.

While the Commission's final report has not yet been made public, a number of interim staff memoranda are available which indicate some of the findings, conclusions, and recommendations to be expected on the subject of materials stockpiling.

Economic Stockpiling.

A 1975 report by the Office of Technology Assessment has concluded that:

1. There is a real potential for suddenly occurring shortages of materials critical to the US economy. The potential is largely the result of import dependence and international competition for materials.

2. Economic stockpiling could be an acceptable means of responding quickly over the short term to the problems of sudden materials shortages. That is, stockpiling can provide a time cushion to allow long-term solutions like substitution to be implemented.

3. Economic stockpiling is only one component of a national materials policy. It should be judged in terms of an overall policy which could include alternate mechanisms.[8]

The National Commission's consideration of policy recommendations related to economic stockpiling has been based on the resolution of two primary issues: specification of the stockpiling objectives*, and basic design of the institutional arrangements for stockpile management. Since the specification of objectives for stockpiling will influence the choice of appropriate institutional arrangements, these issues of objectives and institutions must be resolved sequentially.

The Commission staff has determined economic stockpiling to be a feasible means by which the Government could: (1) protect the general economy against sudden and large disruptions in the supply of critical imported materials; (2) combat potential or actual manipulations of materials prices by foreign producer cartels or by producers with monopoly powers; or (3) stabilize materials prices.

What to stockpile--and how much and in what form--to accomplish the above three objectives have also been considered, and the following rough estimates were developed by the staff to illustrate the probable order of magnitude of the investment required:

(1) For protection against sudden supply disruptions, such as might result from natural disaster or noneconomically motivated political acts (e.g., revolutions or the breakdown of East/West trade), an economic stockpile might hold some large quantity, say, one year's normal supply, of imports of materials of which the principal sources of supply are in Africa and the Soviet Bloc. Under such a policy, only four materials might be stockpiled:

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*The term "objectives" as used here refers to the purposes of the stockpile, not to be confused with objective quantities of materials to be maintained in the stockpile.

chromium, cobalt, manganese and the platinum group metals. The cost of one year's imports of these materials has averaged approximately $652 million during the 1973-75 period, as seen in the following data.

Annual US Imports
(millions of dollars)

	1973	1974	1975 (11 months)
Chromium	62	89	250
Cobalt	53	50	23
Manganese	91	132	197
Platinum Group	237	448	324
Total	443	719	794

(2) An economic stockpile for the purpose of fighting actual or potential materials cartels might also include a year's imports of materials which could be manipulated by producer agreements. (One year's imports is a particularly rough estimate of stockpile requirements in this case.) As a maximum illustrative estimate, annual imports for all basic materials which are imported in a substantial proportion from less developed countries, plus those above, are listed in the following table. The inclusion of an item on this list does not imply any positive probability of cartel actions related to that particular material. The attempt is merely to illustrate a probable maximum investment required. Average annual imports of these commodities during 1973-75 was approximately $1.9 billion.

Selected Critical Imported Materials
Value of Annual US Imports
(millions of dollars)

	1973	1974	1975 (11 months)
Chromium	62	89	250
Cobalt	53	50	23
Platinum Group Metals	237	448	324
Manganese	91	132	197
Alumina	209	304	375
Bauxite	143	157	235
Tin	215	230	326
Natural Rubber	309	434	325
Mercury	12	14	7
Antimony	12	32	21
Bismuth	11	18	10
Columbium	2	3	2
Fluorspar	52	58	55
Mica	2	3	3
Total	1,410	1,972	2,153

Source: Bureau of Census Schedule A Imports Commodity by Country

(3) An economic stockpile used to stabilize materials prices would be considerably larger than either of the above examples. Such a stockpile would contain at least as much material as the previous examples as a buffer against the same contingencies they face, plus material sufficient to achieve price stabilization targets in fluctuating markets. Both the list of materials and the magnitude of stockpile holdings are difficult to estimate even crudely for this objective. Clearly, the undertaking would be very much larger than the previous cases. For instance, simulations undertaken for the State Department estimate that successful stabilization of copper prices over the past 20 years would have required a minimum stockpile investment of $3 billion. A recent study by the Commodities Research Unit suggests that a copper buffer stock could require up to $5 billion of resources. A tin buffer stock might be expected to require about one-fourth that level of resources. These larger

estimates are based on world price stabilization to which the United States would probably contribute only a portion related to its share in world trade of the materials. US investment in such schemes would still be large.

Preliminary Findings of the Commission Staff.

An internal staff report, based on an informal weighing of benefits and costs and with emphasis on practical feasibility, expresses the opinion that creation of a stockpile for the purpose of protection from the impact of actual supply disruptions is deserving of Commission support. With regard to the second purpose, protection against substantial and sudden increases in the prices of key imported materials, support was indicated, but only if it can be arranged as part of an international agreement under which its management could be coordinated internationally and its cost could be shared. In the case of stockpiling for price stabilization, the apparent impracticability of the idea was considered to clearly outweigh its possible theoretical benefits, and rejection was recommended.

While various possible options have been outlined and implications discussed in detail, firm staff recommendations on administrative and institutional arrangements have been deferred pending a Commission decision on the purpose or purposes to be accomplished by a proposed economic stockpile.

The Commission's analysis of economic stockpiling assumes that the policy and management systems which control the Strategic and Critical Materials Stockpile will remain unchanged. In general, the economic stockpile quantity targets should be determined independently of the Critical Materials Stockpile. In the case of stockpiling for price stabilization, however, economic stockpile policy would have to be adjusted to maintain stability in the face of Critical Materials Stockpile operations, as it would for any other exogenous

influence on the market. The economic stockpile policymakers should have a close enough institutional tie to the Critical Materials Stockpile so that they are made immediately aware of all buy or sell decisions of the Critical Materials Stockpile.

The Strategic and Critical Materials Stockpile.

The National Stockpile was established under the Strategic and Critical Materials Stockpiling Act of July 1946 (a revision of PL 117 of 1939) to protect the United States against "costly and dangerous dependence upon foreign sources of supply in a period of national emergency." The administration of the stockpile program has been a target of considerable criticism, with charges of political expediency, unrealistic planning, and a lack of correlation of stockpiling management with mobilization planning and national security strategy. Drastic reductions in the stockpile under policy guidance of the Nixon Administration resulted in the disposal of billions of dollars worth of materials. Stockpile objective quantities of at least 17 critical materials were reduced lower than the minimum mobilization requirement as estimated by the Department of Defense. The Nixon Administration assumption of an uninterrupted supply of imports during an emergency from "all countries not in the war zone or not Communist-oriented" was particularly unrealistic in view of current Soviet maritime strength. A major revision of stockpile planning factors has been announced by the General Services Administration (GSA) which would increase quantities of many of the critical materials presently included in the national stockpile of strategic and critical materials.

In the establishment of separate stockpiles, quantity targets for the critical materials stockpile should not be affected by the existence of an economic stockpile. Defense contingency planning should be based on supply/

demand relations without reference to economic stockpiles, on the assumption that an economic stockpile could be drawn down immediately prior to a defense emergency. Legislation enacting economic stockpiling should clarify the Critical Materials Stockpile legislation in order to prevent any future use of that stockpile for economic purposes.

Strategic Implications

The United States is more self-sufficient in nonenergy mineral resources than most other highly industrialized countries. Our 1973 overall import dependence for these critical industrial materials was only about 15% of consumption, contrasting sharply with the import dependence of Europe (75%) and Japan (90%). Although imports of mineral resources, including energy, constituted less than 1.5% of US GNP for 1973, this was 60% above the nation's dependence a decade ago. It is this rapidly increasing dependence on foreign suppliers, particularly for certain materials critical to our industrial and defense needs, which causes concern. The situation with respect to particular critical materials varies greatly; for example, we have exportable surpluses of phosphate but are totally dependent on foreign tin, manganese and chromium.

The OPEC countries' success in maintaining a cartel that trebled the price of oil in autumn of 1973 suggested the possibility of similar actions by producers of other major commodities. After an initial flurry of dire predictions, however, it became apparent that effective embargoes of other minerals patterned after the oil embargo are unlikely, since other minerals-producing nations do not enjoy the required special combination of circumstances: a small number of producers, large foreign exchange holdings, and a common political or ideological cause.

Collusive pricing will be attempted, and often will be successful in the short term, but normal long-term supply and demand responses in the minerals field, the possibility of using alternative materials, and the diversity of suppliers will thwart long-term success of price-gouging or cartel-like action. In the shorter run, producers may be able to extract considerable price increases before alternate sources and substitution have an impact. It has been suggested that the real price escalation danger could lie with the developed but less industrialized, mineral-rich countries such as Canada, Australia, South Africa and Brazil, which have the financial strength and mineral resource position to have a substantial impact on the marketplace.[9]

The degree of restriction of critical supplies which might result from collusive price increases would not have a serious effect on the military capability of the United States. That portion of US consumption of critical materials required for DoD production activities--approximately 10-20% in wartime and about one-half of that during peacetime--could be met under any foreseeable restrictions of this type. Important secondary effects, affecting the well-being and efficiency of the civilian labor force, might be expected, however, if such supply restrictions were sustained over a prolonged period.

Actual interruptions or cut-offs of supplies could cause serious problems in supporting defense activities during a national emergency. Even though the probability of supply interruptions due to embargoes, civil disturbance, or other political factors may be low, the cost in wartime would be so great that such interruptions must be guarded against.

The critical importance of assuring the flow of strategic materials and preventing Communist control or intimidation of resource areas was emphasized by Vice Admiral John M. Lee, USN (Ret.), in a recent address at the US Naval

War College. Admiral Lee noted that "access to, availability of, and the ability to move essential resources will become the central objective of the strategic equation." He added that this viewpoint implies that "as the resource problem develops, the primary military task after physical defense of the homeland will be to support access to needed resources against constraints, interruptions, or denials, whether imposed by military force, by governmental actions, or by economic effects. It could include denial of resources to hostile states."[10]

The danger of "strategic mineral starvation" of the United States has been discussed in some detail by LTC Henry S. Lang, Jr., in an Air War College research report. Advantages and disadvantages to an adversary nation, in particular the USSR, adopting a mineral starvation strategy are weighed in this study; and effective US actions, including stockpiling, to counter such a strategy are proposed.[11]

Specific Materials.

A number of different criteria have been developed in various attempts to classify materials as to criticality, strategic importance, or vulnerability to coordinated producer action or manipulation. As examples, Yuan-Li Wu attempted to classify materials in terms of their weight and value in world trade and importance to the engineering industry;[12] the Industrial Union Department of the AFL-CIO concentrated on materials essential to industries that are the main sources of manufacturing jobs for US workers;[13] the SSI study referred to above evaluated materials based on availability of domestic reserves, availability of substitutes, number and location of foreign suppliers, ideology of foreign suppliers, and US stockpile quantities.[14]

Regardless of criteria used, certain materials tend to turn up on the "most important," or "most vulnerable" lists. In nine different surveys,

chromium, manganese and aluminum appeared on seven lists of critical materials, while cobalt, nickel, tin and titanium appeared on six lists. Citing manganese alloys as an example, W. J. Kaestner of the US Department of Commerce has called our increasing dependence on imports "a tragic and serious deterioration of the U.S. defense (and industrial) base . . . ."[15] The chromium situation is equally serious, and the American Society for Metals has reported that "chromium-rich countries could, via embargo, political pressure, cartel formation, and so on, seriously affect about 18% of the US manufacturing sector."[16] Albert Speer, the logistics genius of Nazi Germany, has been quoted as saying that chrome--not oil--was the critical material the lack of which led to the destruction of the Third Reich.[17]

Conclusion

Although it is unlikely that shortages of any critical material, chromium, manganese--or even petroleum--will be the direct cause of armed conflict in the foreseeable future, such shortages could certainly exacerbate other areas of international friction and could contribute to the outbreak of hostilities. It is obvious that shortages of certain materials could affect our domestic well-being, and even hamper our war-making potential. The work of the National Commission on Supplies and Shortages represents an important first step in understanding and resolving the many facets of our materials problem. Recommendations in their final report should be given serious consideration by future policy makers, and the solution of materials problems deserves a prominent position in policy decisions and the assignment of national priorities for executive and legislative action.

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APPENDIX A

THE RELATIVE VULNERABILITY INDEX OF CRITICAL MATERIALS

The vulnerability index concept provides a method of assessing, in a semi-quantitative relative way, the susceptibility of materials to supply aberrations related to cartel-like economic pressures, politically motivated coercion or the results of military action. While these threats are obviously not completely additive, they are combined in this simplified assessment of vulnerability to provide a preliminary screening mechanism for the assignment of priorities for more detailed study. A further refinement of the relative vulnerability would involve an analysis of the important influencing factors in terms of long- and short-term effects, and relative importance in war or peacetime. Material vulnerabilities would then vary with different assumed scenarios used in the evaluation. In an earlier report, the relative vulnerability index (RVI) of a number of scarce materials was computed using five factors considered significant in determining vulnerability to coercive or other negative influences. The method has been expanded to provide a computer program for more convenient calculation of RVI's using a larger number of influencing factors.

Methodology. The first step in the RVI determination is the selection of vulnerability-influencing factors, and an assessment of the relative importance of each. Figure A-1 lists the 27 factors used in these calculations, with a qualitative indication of their overall importance in determining the economic, political, or military vulnerability of any materials resource. Next, the direction and magnitude of the effect of each factor are assessed in terms of specific conditions applicable for each selected material (i.e., existing circumstances involving this factor result in: "a significant increase in vulnerability"; "a moderate increase in vulnerability"; or, "a decrease in vulnerability" from some hypothetical zero level). Combining the 'overall importance' and the 'direction and magnitude' symbols will give a matrix as illustrated (in abbreviated form) in Figure A-2 for five factors for four selected critical materials.

Factor	Effect on Vulnerability		L = Large M = Medium S = Small
	Economic	Political	Military
Domestic reserves:			
Availability	L	L	L
Cost of developing	L	L	S
Domestic production industry:			
Present capability	L	L	L
Cost of augmenting	L	L	S
Substitute materials:			
Present availability	L	L	L
Cost of research to develop	L	L	S
Time required to develop	L	L	L
Additional domestic resources:			
Present availability	L	L	L
Cost to develop suitable processes	L	M	M
Time to develop suitable processes	M	M	M
Probability of discovery if not available	M	M	S
Cost of additional exploration	M	M	S
Foreign suppliers:			
Number of controlling companies	L	S	M
Number of supplier countries	M	L	M
Political stability of supplier countries	M	L	M
Ideology of supplier countries	L	L	L
Productive capacity of supplier countries	L	L	L
Economic sufficiency of supplier countries	L	L	S
History of political relations with US	S	M	S
US dollar involvement in supplier country	M	M	S
Accessibility of supplier countries (supply routes)	S	S	L
US stockpile:			
Present US stockpile objective	L	L	L
Actual quantity in US stockpile	M	M	M
Customary industry stockpile	M	M	M
Trend in usage of critical material	M	M	S
Proportion of national consumption directly related to military requirements	S	S	L
Importance of secondary sources (recycling)	M	M	M

Figure A-1. Factors Affecting Commodity Relative Vulnerability Index

	(Economic) (Political) (Military)	Availability of Domestic Reserves	Availability of Substitutes	Number of Foreign Suppliers	Ideology of Foreign Suppliers	US Stockpile Objective
Aluminum (Bauxite)	(E)	LI	LI	MI	LD	Li
	(P)	LI	Li	LD	LD	Li
	(M)	Li	Li	Mi	LD	Li
Chromium	(E)	LI	LI	Mi	Li	LI
	(P)	LI	LI	Li	LD	LI
	(M)	LI	LI	MI	LD	LI
Cobalt	(E)	Li	Li	Mi	Li	LD
	(P)	Li	Li	Li	Li	LD
	(M)	LD	Li	Mi	Li	LD
Manganese	(E)	LI	LI	Mi	LD	Li
	(P)	LI	LI	LD	LD	Li
	(M)	Li	LI	Mi	LD	LD

Legend: Vulnerability-influencing Factors.

Overall Importance: (Effect on Vulnerability)

L = Large
M = Medium
S = Small

Direction and Magnitude of Influence: (Existing Circumstances)

I = A significant increase in vulnerability
i = A moderate increase in vulnerability
D = A decrease in vulnerability

Figure A-2. Example of Qualitative Matrix Used in Determination of Relative Vulnerability Index

To quantify vulnerabilities, numerical values are assigned to the above symbols, multiplied together for each factor, and factor values added for each material. This results in a "relative vulnerability index"--relative, because it cannot be considered an absolute measure of vulnerability, but only an indication of which materials should be considered more critical in the assignment of priorities for R&D, stockpiling, or other remedial measures.

Figure A-3 illustrates an RVI calculation for chromium.

The assignment of numerical values to the 'overall importance' and 'direction and magnitude' factors is at best a subjective determination in the RVI computation, and the more realistic these values are, the more accurately will the RVI reflect actual conditions. Values used in this report are based solely on the considered judgment of the author. They could undoubtedly be refined and their validity improved by the use of a modified Delphi or similar technique, involving a number of expert opinions in the areas concerned.

Results of a 27-factor computation for four critical materials are depicted in Figure A-4.

		Availability of Domestic Reserves	Availability of Substitutes	Number of Foreign Suppliers	Ideology of Foreign Suppliers	US Stockpile Objective	RVI
CHROMIUM	Economic	LI=100	LI=100	Mi=25	Li=50	LI=100	375
	Political	LI=100	LI=100	Li=50	LD=0	LI=100	350
	Military	LI=100	LI=100	MI=50	LD=0	LI=100	350
					OVERALL RVI		1075

Legend: Numerical Values.

L = 10; I = 10	LI = 100
M = 5; i = 5	Li = MI = 50
S = 1; D = 0	Mi = 25
	SI = 10
	Si = 5
	D = 0

Figure A-3. RVI Calculation for Chromium, Using Five Factors

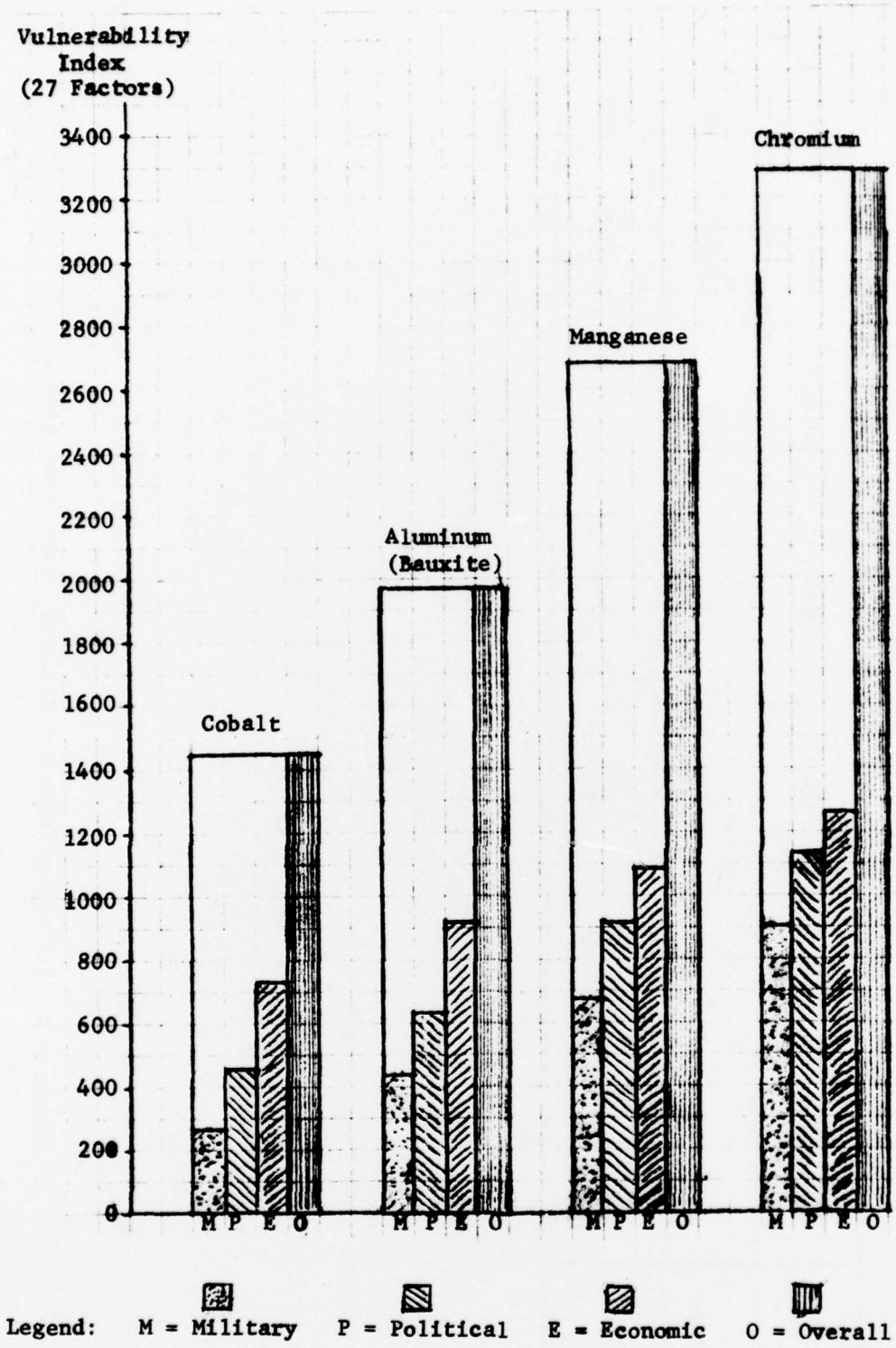

Figure A-4. Vulnerability to Coercion of Selected Scarce Materials

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ACN 76050

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): (6) Materials Vulnerability of the United States--An Update,

5. TYPE OF REPORT & PERIOD COVERED: (9) Special Report,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): (10) Alwyn H. King

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Strategic Studies Institute
US Army War College
Carlisle Barracks, PA 17013

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

(11) 12. REPORT DATE: 30 Apr[illegible] 77

13. NUMBER OF PAGES: 26 (12) 33p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Materials; scarce resources; National Commission on Supplies and Shortages; national stockpile; Relative Vulnerability Index.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This special report discusses the problem of availability of nonenergy materials in the United States, and reviews some recent Government and industry efforts to deal with the situation. The US materials dilemma involves issues more complex than simply a scarcity of certain materials, or monopolistic and coercive actions by foreign materials suppliers. Materials availability problems include insufficient R&D to develop

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

new resources, extraction processes and substitutes; inadequate recycling; and the lack of an established dialogue between the materials R&D and the materials supply and demand communities.

The work of the National Commission on Supplies and Shortages is discussed, particularly with regard to materials stockpile planning.

An appendix to the memorandum describes the current status of the Strategic Studies Institute method of determining a "relative vulnerability index (RVI)" by which critical materials may be classified as to vulnerability to military, political, or economic pressures.